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DETERMINATION OF THE DEPTH OF THE
MILKY WAY.

By T. J. J. SEE.

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INTRODUCTORY REMARKS.

The problem of determining the depth of the Milky Way, as accurately as possible, is one which has now engaged my attention for over twenty years, and I will therefore take this occasion to bring together the results at which I have arrived, partly because they are of high general interest, and partly because the progress thus made will prove instructive as to the methods which must be adopted for the measurement of the distances of the most remote objects of the sidereal universe. Here we have to deal with distances so immense that the method of annual parallaxes, commonly used for the stars comparatively near the sun, utterly fails; and recourse must be had to other methods which will serve for the greatest distances to which our modern giant telescopes can penetrate.

Alpha Centauri, the nearest of the fixed stars, was also the first to be successfully measured for parallax, by Thomas Henderson, of the Cape of Good Hope, in 1831; but the work was not reduced till January, 1839, and meanwhile Bessel had measured the parallax of 61 Cygni in 1838 and promptly published the result of his triumph.

Of late years astronomers have given greatly increased attention to the question of the distances of the stars, and systematic campaigns of the most laborious kind have been carried on by Gill; Elkin and Chase, of Yale; Kapteyn, of Groningen; and Schlesinger, at the Yerkes Observatory, Chicago. Some 350 stars have now been studied by the standard method of parallaxes, and for most of these objects, perhaps about 200 in number, fairly satisfactory data have been deduced; but the method can be extended only to stars within less than 100 light-years of our sun, and is therefore very limited in its applicability, owing to the small diameter of the earth's orbit, and the insensible effects of the annual displacements resulting from the orbital motion of our planet. As nature herself has fixed the limits of this method, astronomers have naturally cast about for other methods of greater generality and have finally developed processes of surprising power, of which an account will be given in the present paper.

§ 1. OUTLINE OF THE METHODS ADOPTED.

Among previous investigators who have occupied themselves with the difficult problem of the profundity of the Milky Way the first place will be universally assigned to the incomparable Sir William Herschel, who extended his researches over many years, and reached results which were for a time accepted, but have been rejected for three quarters of a century, and yet are now proved to be essentially correct. It is very remarkable and exceedingly unfortunate that Herschel's conclusions have been generally rejected by his son, Sir John Herschel, and other astronomers during the past seventy-five years. But before discussing the circumstances which led to this outcome I shall recall the modern attempts at the solution of the problem of determining distances in the Milky Way.

After the spectroscope came into use and Huggins had applied Doeppler's principle to the motion in the line of sight (1868) it was pointed out by Fox Talbot in 1871 (*Brit. Assoc. Report*, 1871, p. 34, Pt. II.) that the possibility existed of determining the absolute dimensions of the orbit of a pair of binary stars which had a known

angular dimension in the sky, and thus parallaxes might be found of systems very remote from the earth. In 1890, while a post-graduate student at the University of Berlin, I developed this method still further, and showed how it could be used also to test the accuracy of the law of universal gravitation in the stellar systems. The spectroscopic method then outlined was brought to more general form in 1895, and it at once occurred to me to point out its use for measuring the distance of clusters in the Milky Way (A. N. 3,323), as more certain than Herschel's method of star gauges.

Our age is one of rapid improvement in all scientific processes, and during the past sixteen years naturally much progress has been made in double-star astronomy, as well as in our knowledge of nebulae and clusters. On looking more closely into the spectroscopic method, which in 1895 had been shown to be applicable to objects 1,000 light-years from the sun, and might thus include all suitable double stars within this sphere, I became convinced that while it is a great theoretical advance over the old method of parallaxes, it still is quite inadequate for finding the distances of the most remote objects in the sidereal universe. Accordingly in 1909 I returned to the improvement of Herschel's method as the most promising, for the determination of the distances of *the most remote objects*. Here are the grounds for this decision:

1. It was noticed, as remarked by Burnham, that revolving double stars are rare, if not unknown, in clusters, and among the star-clouds of the Milky Way—not because such systems are not present in these masses of stars, but because they cannot be separated, owing to the great distances at which these masses of stars are removed from us.

2. When double stars cannot be clearly separated in the telescope they cannot be used for parallax by the spectroscopic method; and thus the spectroscopic method, while having a wider range of application than the method of parallaxes, in something like the ratio of the size of the double star orbit to that of the orbit of the earth, is yet applicable only to stars within about 1,000 light-years of our sun.

3. It will be shown below that the most remote stars are separated from us by a distance of at least 1,000,000 light-years, and as this space is a thousand times that to which the spectroscopic method may be applied, it follows that there is no way of fathoming these immense distances except by the improvement of the method of Herschel.

And just as in my "Researches on the Evolution of the Stellar Systems," Vol. II., 1910, p. 638, I had been able to adduce substantial grounds for returning to the vast distances calculated by Herschel, so also during the past year I have been able to add to the proof there brought forward, and will proceed to develop it in the present paper.

§ 2. HERSCHEL'S METHOD DEPENDING ON THE SPACE PENETRATING POWER OF TELESCOPES.

In his celebrated star gauges Herschel employed a twenty-foot reflector of 18 inches aperture, and calculated the space-penetrating power of such an instrument from the ratio of the aperture of the telescope to that of the pupil of the eye. The comparative distance to which a star would have to be removed in order that it may appear of the same brightness through the telescope as it did before to the naked eye may thus be calculated. Herschel found the power of this 20-foot reflector to be 75; so that a star of 6th magnitude removed to 75 times its present distance would therefore still be visible, as a star, in the instrument.

Admitting such a 6th magnitude star to give only a hundredth part of the light of the standard first magnitude star, it will follow that the standard star could be seen as a sixth magnitude star at ten times its present distance; and if we then multiply by the space penetrating power, we get 750 as the distance to which the standard star could be removed and still excite in the eye, when viewed through the telescope, the same impression as a star of 6th magnitude does to the naked eye. Thus if Alpha Centauri be distant 4.5 light-years, it would be visible in Herschel's telescope at a distance of 3,375 light-years. This is about the distance ascribed to the

remoter stars of the Milky Way by Newcomb and many other modern writers; but of course it is much too small, for the following reasons:

(a) Newcomb and other astronomers cite the possibility of some of the stars being as much as 1,000,000 times brighter than the average solar star, and in that case the star might be seen at $\sqrt{1,000,000} = 1,000$ times that distance, or 3,375,000 light-years, with an instrument having a space penetrating power no greater than that employed by Herschel, provided that no light is extinguished in its passage through space.

(b) If the telescope be more powerful than Herschel's 20-foot reflector, the light gathered will be increased in the ratio of $x^2/(18)^2$, where x = diameter of mirror; and for the 60-inch reflector at Pasadena, $x = 60$, over nine times as much light could be gathered, or stars seen over three times as far away. Thus if the stars have only about 10,000 times the luminosity of the sun, they could still be seen with the Pasadena reflector at a distance of over a million light-years. For $3,375 \text{ l.-y.} \times 3 \times 100 = 1,012,500$ light-years.

(c) The sensitiveness and accumulative effects of the photographic plate, will enable us to extend our sounding line still further out into space by some three magnitudes, or four times the distance; and thus with a modern 60-inch reflector we could photograph stars at a distance of about four million light-years, if they have 10,000 times the standard solar luminosity, and no light is lost in space. How much light is really lost in space will be considered later, but it may be stated here that it probably is decidedly less than was concluded by Struve.

§ 3. INDEPENDENT CALCULATION OF THE DISTANCE OF THE REMOTEST STARS OF THE HELIUM TYPE.

From the data given in *Lick Observatory Bulletin* No. 195, we find that 225 helium stars employed by Campbell in his line of sight work have an average visual magnitude of 4.14. Of the four variables given in this *Bulletin*, we have used the maximum brightness in three cases, because they are of the algal type. In the case

of u Herculis, we have used the mean magnitude, because the type of variable does not appear to be as yet well established.

Here then we have 225 helium stars at an average distance of about 540 light-years. For in *Lick Observatory Bulletin* No. 195, p. 121, Campbell finds the 180 class B, or helium, stars to have an average distance of 543 light-years, while in *Publications of the Astronomical Society of the Pacific* for June–August, 1911, p. 159, Professor Curtis gives 534 light-years as the average distance of 312 helium stars. The former distance for 180 stars being greater than the latter distance for 312 stars, we may take 540 light-years as the distance of the 225 helium stars here under discussion, the average magnitude of which is 4.14.

If the average magnitude were decreased to 21.14, by removal to 2,512 times their present distance, which would reduce the average brightness by 17 magnitudes, the distance of the stars would be multiplied by 2,512, and become 1,356,480 light years. This is for the helium stars as they are, without any hypothesis as to brightness, or as to the extinction of light in space, which will be considered later.

The question will naturally be asked whether helium stars really exist at these great distances. We may unhesitatingly affirm that they do, because of the well-known whiteness of the small stars of the Milky Way. It is true that Pickering has investigated the distribution of the helium stars in the *Harvard Annals*, Vol. 56, No. II., and Campbell quotes these data in *Lick Observatory Bulletin* No. 195 as showing that the helium stars are all bright objects. Pickering believed his tabulations to indicate "that of the bright stars, one out of four belongs to this class (B), while of the stars of the sixth magnitude there is only one out of twenty; and that few if any would be found fainter than the seventh or eighth magnitude." The implication here is that no helium stars exist at very great distances corresponding to small magnitudes; but of course such a view is untenable.

It probably is true that the group of helium stars at a distance of some 540 light-years from our sun, and thus comparatively near

us, does cease after a certain faintness and distance has been reached; but is equally certain that other clusters or clouds of helium stars recur at greater distances, among the millions of small white stars constituting the Milky Way. For as Herschel long ago noticed the Galaxy is everywhere observed to traverse the circuit of the heavens in a *clustering stream*; and our view of it from the region of the sun is not essentially different from the view that could be obtained from other points in this starry stratum. Add to this consideration the fact of the well-known whiteness of the small stars in the Milky Way, and we are authorized to conclude that an indefinite number of clusters or groups of helium stars will be found in the Milky Way, and thus such stars will certainly exist at the greatest depths to which our giant telescopes can penetrate.

We must therefore be on our guard against the superficial view, that because the helium stars near the sun fade away as the sixth magnitude is approached, other groups of stars of this type do not occur at greater distances. The typical whiteness of the millions of small stars which make up the Milky Way, and the clustering character of that magnificent collection of stars, alike forbid any such inference.

Herschel had the correct view of the constitution of the Galaxy a century ago. Unfortunately his works have been very inaccessible, and are so little used that many erroneous conceptions have been given currency by more superficial investigators. It is impossible to commend too highly the movement now on foot in England to reissue the collected works of Sir William Herschel. In all that pertains to the sidereal universe as a whole he is easily the greatest of all modern astronomers, and will always remain unrivaled.

§ 4. EXPLANATION OF THE METHODS EMPLOYED BY CAMPBELL FOR FINDING THE AVERAGE DISTANCE OF THE GROUP OF NAKED EYE HELIUM STARS.

This is essentially a combination of the line of sight motion as found at Lick Observatory, with the proper motions resulting from observations with the meridian circle, by many observers, as worked

up by Boss of the Dudley Observatory, Albany, New York. By the recent study of several thousand of the brighter stars included in his Preliminary General Catalogue, Professor Boss has deduced their proper motions with a high degree of accuracy. Campbell found from 180 of these stars resembling our sun in spectral type that their average cross proper motion in the sky, from the values derived by Boss, was about 0.11 second of arc per annum, while at the same time their average speed in the line of sight shown by the spectrograph at Lick Observatory was 8.9 miles per second, or two hundred and eighty million miles a year. Having the average motion in the line of sight, in absolute units, and the average cross proper motion in seconds of arc, it is easy to find how far away a base line of 280 million miles would have to be to subtend an angle of 0.11 of a second of arc. It turns out to be ninety-two light-years.

In this way it is possible to get the average distances of large groups of stars. Here are some of the results found by Campbell.

Type.	No.	Average Yearly Cross-motion.	Average Radial Velocity in Miles per Second.	Average Relative Parallax.	Average Distance in Light-years.
B-B ₅	312	0.0078	3.9	0.0061	534
B ₈ -B ₉	90	0.0182	4.2	0.0129	253
A	172	0.0368	6.5	0.0166	196
F	180	0.1075	8.9	0.0354	92
G	118	0.0748	9.9	0.0223	146
K	346	0.0516	10.4	0.0146	223
M	71	0.0384	10.6	0.0106	308

This table contains the most important results of the Campbell-Boss method of obtaining average distances for large groups of stars. It need scarcely be remarked that its significance can hardly be overrated. But whilst the *average values* given are quite trustworthy, the method is of course inapplicable to the *individual stars*; and if their distances are to be found recourse would have to be had to the standard method of parallaxes, or to the spectroscopic method in the case of visual binaries.

§ 5. SOME OF THE DISTANCES OF THE REMOTEST STARS AS
HERETOFORE CALCULATED BY ASTRONOMERS.

1. Sir William Herschel, *Phil. Trans.*, 1802, p. 498, "almost 2,000,000 light-years."
2. Sir John Herschel, "Outlines," edition of 1869, p. 583, "upwards of 2,000 light-years."
3. Guillemin, "The Heavens," trans. by Lockyer, 1867, p. 433, "upwards of 20,000 light-years."
4. Bartlett, "Spherical Astronomy," 1874, p. 149, "upwards of 2,437.5 light-years."
5. Newcomb, "Popular Astronomy," edition of 1878, p. 481, "about 14,000 light-years" (for the Herschel stars).
6. Clerke, "System of the Stars," 1890, p. 314, "less than 36,000 light-years."
7. Ranyard, "Old and New Astronomy," 1892, p. 748, "less than 70,000 light-years."
8. Young, "General Astronomy," edition of 1904, p. 563, "10,000 to 20,000 light-years."
9. Newcomb, "The Stars," 1908, p. 319, "at least 3,000 light-years."
10. See, "Researches," Vol. II., 1910, p. 638, "4,500,000 light-years."

From this table it will be seen that there was a great falling off in the distances following the epoch of Sir William Herschel; and that the present writer was the first to recognize the fallacy of the recent estimates of distance, and to restore the large values used by that unrivaled astronomer one hundred and ten years ago. Here we have a good illustration of the retrogradation of opinion in astronomy, under the cultivation of inferior genius. Sir John Herschel's preference for such small distances over the large values used by his father is indeed remarkable and very regrettable. Evidently the small value used by Newcomb is simply an echo of the reduction in distance made by Sir John Herschel. The absurdity of these small values—not over five times that of the helium stars of 4.14 magnitude investigated at Lick Observatory—ought to impress us with the small importance to be attached to any opinion merely because it is currently accepted. Thus we have a clear case of misleading tradition transmitted from the second Herschel, and the amazing spectacle of the whole world using values about a thousand times too small, for the greater part of a century, in times which were supposed to be very enlightened! Strange indeed that the correct work

of the great Sir William Herschel should have been neglected all this time! Will it seem credible to future ages that such a remarkable retrogradation of opinion could have occurred and persisted during the nineteenth and twentieth centuries? If so, it must be attributed to the narrowing effects of extreme specialization, which, with the advance of science, has been difficult to avoid in our time, and yet is utterly disastrous to the growth of true natural philosophy as the study of nature in the widest sense.

§ 6. OTHER METHODS FOR CONFIRMING THE GREAT DEPTH OF THE MILKY WAY.

(a) The girdle of helium stars about our sun, according to the Lick determination, has a mean distance of 540 light-years, or a mean diameter of 1,080 light-years. If this be one twentieth of the average thickness of the Milky Way stratum, as one may infer from the appearance of certain clusters in the constellation Sagittarius, which are near enough to be studied intelligently, then we have 21,600 light-years for the average thickness of the Milky Way.

Now when we traverse the Milky Way from Centaurus to Cepheus, over an arc of 180° in length, the central band appears to the naked eye to have a width of 3° or 4° , as was long ago remarked also by Herschel and Struve. This is an extension along the circle of the Galaxy of about 60 times its thickness. If then the thickness be 21,600 light-years, the double depth of the stratum in both directions becomes about two thirds of $21,600 \times 60 = 864,000$ light-years. And if only the faint or distant telescopic stars be considered, the width of their belt of distribution is narrower, and the depth would be found several times greater yet. Wherefore it seems certain that the profundity of the Milky Way, considerably exceeds a million light-years, and may be several times that depth.

(b) Accordingly if we make the very moderate hypothesis that the width of 3° or 4° , which was also noticed by Herschel and Struve, represents chiefly the nearer portion of the Galaxy; and that the remoter portion has a width not exceeding 1° , we should conclude that the depth may be found by multiplying the thickness

or apparent angular width of 21,600 light-years by the number of degrees in the radius, 57.3. This gives for the depth 1,237,680 light-years, and this value might be considerably increased by adjustments in the data which are not improbable.

(c) In addition to these general arguments, founded on the principles of geometry, we might introduce another based on actual measurement. The Lick helium stars, of average brightness 4.14 mag., were found to have an average distance of 540 light-years. If they were brought near enough to us to appear of 1st magnitude, this distance would have to be divided by $4 = \sqrt{(2.512)^3}$, and thus we find for the first magnitude helium stars a distance of 135 light-years.

Now in calculating the plan of the construction of the heavens, from the apparent breadth of the Milky Way, Herschel arrived at the conclusion that the thickness of the stratum is about 80 times greater than the diameter of the sphere including the first magnitude stars represented by Sirius (*Phil. Trans.*, 1785, p. 254). And if the average distance of these stars be taken as 135 light-years, the mean diameter of the shell in which they are included will be 270 light-years. This would give exactly 21,600 light-years for the thickness of the stratum of the Milky Way, as before.

It is true that Herschel classed all first magnitude stars in one group, and took no account of the fact that the helium stars are the more remote and the more brilliant; yet regarding the Galaxy as a stratum of stars chiefly of the helium type, which certainly is true of all the more distant portions of that magnificent collection of stars, we may consider the reasoning of this great astronomer as still valid. And the argument in regard to the depth of the Milky Way is thus the same as that given above under (a) and (b).

§ 7. THE EFFECTS OF THE EXTINCTION OF LIGHT IN SPACE.

This problem has been treated with some detail in the 23d chapter of my "Researches," Vol. II., 1910, but we shall here examine the subject with greater care, especially as to the most probable average value of the coefficient of extinction. The light was shown

by Struve to be defined by the equation

$$\xi = \frac{1}{x^2} (0.990651)^{x-1}, \quad (1)$$

where x is the distance of the star, in units of $\Delta = \sqrt{(2.512)^n}$ and n is the difference in magnitude. At very great distances nearly all the light is cut off, and it therefore becomes a question of high importance to determine as accurately as possible the proper value for the coefficient of extinction.

Struve's value, used in the above formula, seems to be too large, and I have therefore calculated a new table, to show the effect of decreasing the coefficient. In justification of this course it should be recalled that Sir William Herschel ignored extinction entirely; but while this procedure obviously is defective, it is pretty clear, from the aspects of the Milky Way as now made known by modern research, that Struve's coefficient is decidedly too large. The following table shows the effects of varying the coefficient, upon stars 17 magnitudes fainter, corresponding to a distance 2,512 times larger, where $x - 1 = 2,511$.

TABLE FOR VARYING COEFFICIENT OF EXTINCTION.

λ = Coeff. of Extinction.	$\lambda x - 1$.	Fractional Part of Light Transmitted, in Spite of Extinction.
0.990651	0.000,000,000,05709	$\frac{1}{17514\ 000\ 000}$ (Struve's value)
0.995	0.000,003,4072	$\frac{1}{293\ 490}$
0.996	0.000,042,571	$\frac{1}{23490}$
0.997	0.000,52923	$\frac{1}{1889.5}$
0.998	0.006,5567	$\frac{1}{152.51}$
0.999	0.081,091	$\frac{1}{12.332}$ (See's value)
0.9995	0.284,846	$\frac{1}{3.5107}$
1.00000	1.000,00	1.00000 (Herschel's value)

From the study of this table, we perceive that at the distance

$x = 2,512$, corresponding to an enfeeblement of 17 magnitudes, from mere increase of distance alone, the extinction of light varies from almost total loss, with Struve's coefficient, to no loss whatever, on Herschel's tacit hypothesis of zero extinction. This latter view, however, certainly is extreme, and probably all modern astronomers agree that there is extinction of light due to cosmical dust in space. A hazy background of dust is shown on the photographs of the Milky Way and other portions of the sky, and proved to pervade the solar system by the universal prevalence of meteors.

Since, however, both comets and nebulae are found to be extremely tenuous bodies, and observed to transmit the light of stars with but excessively slight enfeeblement, it is obvious that the general extinction will be much smaller still, but yet appreciable. I have therefore adopted a coefficient of 0.999, about one hundredth larger than Struve's, as best harmonizing all known phenomena. This value, it is true, is much nearer to Herschel's than to Struve's coefficient, yet it admits an extinction of light which becomes appreciable at great distances, while for moderate distances it is nearly insensible; and I believe this to correspond closely with all the known facts of the sidereal universe.

An enfeeblement of one twelfth at a distance appropriate to stars 17 magnitudes fainter, could easily be compensated for by a corresponding abnormal brilliancy of the remotest stars, which on several grounds seems to be highly probable. Thus our procedure involves no extravagant assumptions as to the great brightness of the most distant stars, or as to large extinction of light, while on the other hand it avoids Herschel's tacit hypothesis of zero extinction, which certainly is unjustifiable.¹

¹ In an important paper read to the Bavarian Academy of Sciences, June 10, 1911, p. 459, Professor H. von Seeliger likewise reaches the conclusion that the absorption is very small, amounting to 0.34 of a magnitude at 780 times the distance of Sirius, which Seeliger takes for the border of the sidereal system.

§ 8. A GRAPHICAL METHOD FOR DETERMINING THE DEPTH OF THE GALAXY, BASED ON THE STUDY OF CLUSTERS.

1. Make a diagram of 10 or 20 concentric circles, separated by equal intervals, each corresponding to 100 million light-years. In this scheme no clusters will be included within the central circle, because the actual measurements for parallax have excluded this possibility. But the various clusters of the N.G.C. may be plotted within the outer circles, or beyond them all, according to the results given by Herschel's rule of brightness.

2. It is required therefore to locate the clusters, and to indicate their apparent angular diameters by dots of appropriate size. Some allowance must of course be made for the varying stages of development of the different clusters, but if there is a decreasing angular diameter with distance it may be held that the method of estimating distance devised by Herschel is essentially valid, and in fact our only method of fathoming these immense distances, and thus determining the depth or profundity of the Milky Way.

3. A careful attempt has been made to apply this method, using the data of the N.G.C., and the results of the Crossley photographs recently obtained at Lick Observatory. The results of this investigation are shown to confirm the present theory.

§ 9. FINAL TEST OF THE INDEFINITE EXTENSION OF THE MILKY WAY DESIRABLE.

This should be made by the graphical method just outlined, but by means of more powerful instruments than any yet systematically employed in this work. To feel satisfied that the universe extends on indefinitely, we must have proof of additional clusters of stars of smaller magnitude, and more compressed constitution, as from the narrowing effect of perspective, at great distances. Probably we shall not know what the sidereal heavens contain in the way of *vanishing clusters* till the Milky Way is systematically photographed for just such objects, and this very likely will require a long campaign of photographic research with a large instrument. But as many large reflectors are now coming into use, we may hope for it

before many years elapse. This would be completing on a modern scale the sidereal soundings left somewhat incomplete by the systematic explorations of the Herschels.

In a private letter, written in response to my recent inquiry regarding the power of the 60-inch reflector of the Solar Observatory at Mt. Wilson, Professor W. S. Adams, the Acting Director, informs me that this fine instrument probably will show visually stars as faint as 18th magnitude. He points out, however, that the magnitude scale is not well defined for such faint objects, and that very few astronomers have enough experience to fix it at the present time.

Adams also informs me that from a photograph of the region of the northern celestial pole of four hours' duration, Professor E. C. Pickering has derived a value of 21.0 magnitude for the faintest stars, by the system of photographic magnitudes in use at the Harvard College Observatory. Obviously there is some uncertainty in this value, but it probably is not extreme.

In answer to an inquiry as to the possibility of getting still fainter stars by prolonging the exposure, Professor Adams assures me that it can be easily done, the only limit being the brightness of the background of the sky; but that with the clear air of Mt. Wilson this would not be reached till the exposure had extended over many hours. He adds that it takes about three times the exposure to obtain a star one magnitude fainter. From the data here supplied it seems certain that stars as faint as 21.0 magnitude may be photographed at Mt. Wilson, with the 60-inch reflector, and that by prolonging the exposure several additional hours or through whole nights, stars of 22.0 magnitude probably could be obtained.

It is therefore well established that stars 17 magnitudes fainter than the 225 helium stars, with average magnitude of 4.14, recently investigated at Lick Observatory, may now be photographed with more than one instrument; and the value of $\Delta=2,512$ used in our calculations is amply justified. In fact it seems probable that instead of 2,512 as our distance multiplier for stars 17 magnitudes fainter, we might have used the larger value 3,981, corresponding to stars 18 magnitudes fainter than our 225 helium stars with average magni-

tude of 4.14. This would almost have doubled the calculated depths of the Milky Way throughout the foregoing discussion, and given us over two million light-years, exceeding the profundity originally concluded by Herschel in 1802. In the *Phil. Trans.* for 1800, pp. 83-4, Herschel finds by a different process that a cluster of 5,000 stars visible in his 40-foot telescope is distant 11,765,475,948,678,-678,679 miles, "a number which exceeds the distance of the nearest fixed star at least three hundred thousand times." With modern data this proves to be 460,355 times the distance of Alpha Centauri, or 2,001,120 light-years.

§ 10. SUMMARY OF THE CHIEF RESULTS OF THE DETERMINATION OF THE DEPTH OF THE MILKY WAY.

From the several independent and mutually confirmatory arguments here adduced it follows that the depth of the Milky Way decidedly exceeds a million light-years, and substantially accords with the profundity concluded by the illustrious Herschel one hundred and ten years ago.

1. Herschel concluded that with his forty-foot reflector he perceived stars whose light had occupied two million years in reaching the earth; and he justly remarked that he had seen further into space than any human being before him. The visual power or light grasp of Herschel's telescope is somewhat surpassed by modern instruments; and much additional power is given to the modern instrument by the use of photography.

2. But if, on the one hand, the modern instruments surpass Herschel's in power, there is on the other some increased need for this in that we now attempt to take account of the extinction of light by cosmical dust in space. Neglecting this loss of light, Herschel may have slightly overestimated the distances to which his telescope could penetrate, but the error was scarcely of sensible importance.

3. With our greatest modern instruments and the use of photography it is certain that we can observe stars² at a distance of over

² In *Astron Nachr.*, No. 4,536, Nov. 13, 1911, Professor F. W. Very concludes that the *White Nebulæ* may be galaxies at a distance of a million light-

two million light-years, and it is very probable that we can penetrate to a depth of about five million light-years. A modern silver-on-glass reflector of twelve feet aperture would give about six times as much light as the 60-inch reflector at Pasadena, and with this gain of two magnitudes in light power it is probable that we could penetrate into space at least twice this distance (theoretically 2.512 is the factor) or *to a depth from which the light would take ten million years to reach the earth.*

At the present time a 12-foot reflector is possible, and the depth to which we can penetrate is simply a question of telescopic power, which can be vastly but not indefinitely increased. And this is true in spite of the extinction of light by cosmical dust in space. There is a limit to the distance to which any given telescope can penetrate, but it increases steadily with the aperture, since the only question involved is one of enormous light grasp.

It is to be hoped that a telescope of not less than 12 feet aperture may be built for use on the Milky Way. With such a giant instrument discoveries of the highest order might confidently be anticipated. A modern expansion of our views of the sidereal universe analogous to that which marked the great epoch of Herschel would follow, with the most beneficial effects upon every branch of astronomical science. Recent developments in many lines show that the epoch of great discoveries has not passed, but is in fact just beginning: and the estimates here laid down, as to the depth and magnificent extent of the Milky Way, convey to us but a dim outline of the discoveries which await the builders of the giant telescopes of the future. In this great advance America may naturally be expected to take the leading part.

STARLIGHT, ON LOUITRE,
MONTGOMERY CITY, MISSOURI,
November 4, 1911.

years. The view adopted in my "Researches," Vol. II., 1910, however, is much more probable, since it gives continuity to the various types of bodies observed to constitute the sidereal universe. Note added Dec. 16, 1911.